

Relative Luminosity Measurement in STAR and Implications for Spin Asymmetry Determinations

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Relative Luminosity at STAR - Motivation

Double spin longitudinal asymmetry (e.g. $p+p \rightarrow \text{jet} + X$) is defined as:

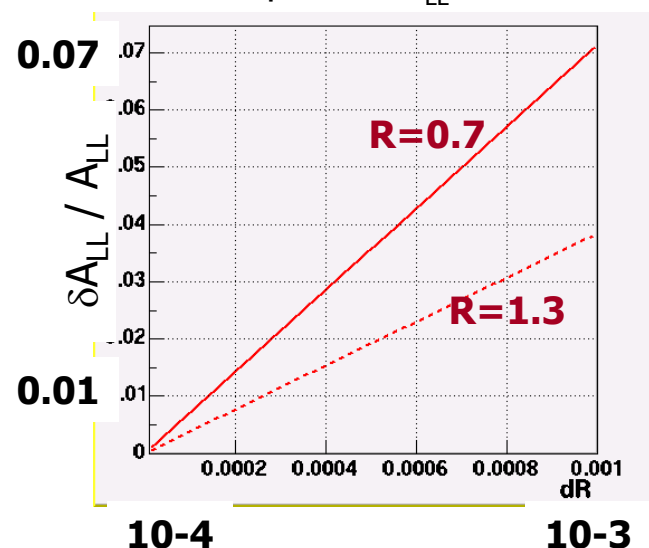
$$A_{LL} = \frac{1}{P^2} \times \frac{(N_{\uparrow\uparrow} + R_1 N_{\downarrow\downarrow}) - (R_2 N_{\downarrow\uparrow} + R_3 N_{\uparrow\downarrow})}{(N_{\uparrow\uparrow} + R_1 N_{\downarrow\downarrow}) + (R_2 N_{\downarrow\uparrow} + R_3 N_{\uparrow\downarrow})}$$

P – beam polarization, from CNI polarimetry at RHIC

N_i where $i = \uparrow\uparrow, \uparrow\downarrow, \downarrow\uparrow, \downarrow\downarrow$ – spin dependent yields and $R_{1(2,3)}$ – relative luminosities:

$$R_1 = \frac{\mathcal{L}_{\uparrow\uparrow}}{\mathcal{L}_{\downarrow\downarrow}}, \quad R_2 = \frac{\mathcal{L}_{\uparrow\uparrow}}{\mathcal{L}_{\downarrow\uparrow}} \quad \text{and} \quad R_3 = \frac{\mathcal{L}_{\uparrow\uparrow}}{\mathcal{L}_{\uparrow\downarrow}}$$

Assumption: $A_{LL} = 0.01$



Requirements for a luminosity process/detector:

- high rates
- small background
- no (or small) spin dependence
(longitudinal polarization)

$$\delta R \ll P^2 \times A_{LL}$$

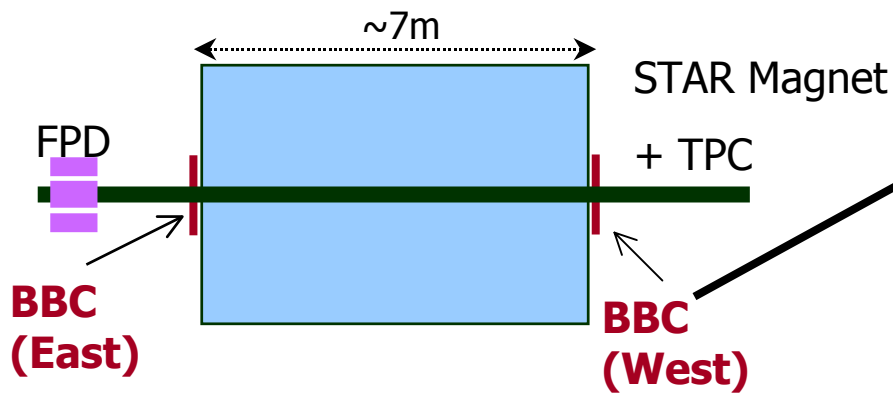
Analysis done with STAR data at $\sqrt{s}=200$ GeV
with transverse proton beam polarization

Important for preparation for the next RHIC run with longitudinal beam polarization ! 2

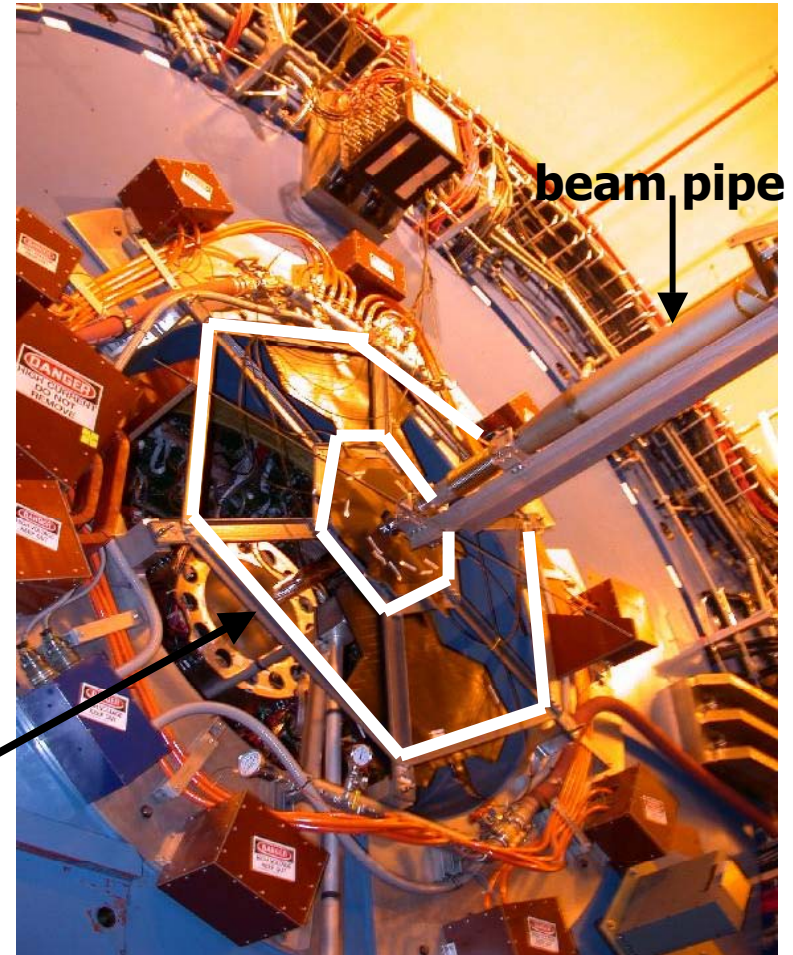
Beam-Beam Counter (BBC)

- luminosity monitoring detector at STAR

Scintillator annulus installed around the beam pipe, on the east and west poletips of STAR magnet at $\pm 3.5\text{m}$ from IR ($2 < |\eta| < 5$)



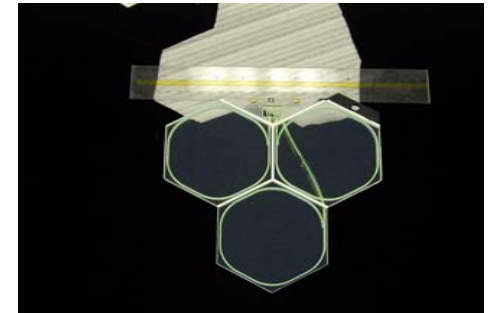
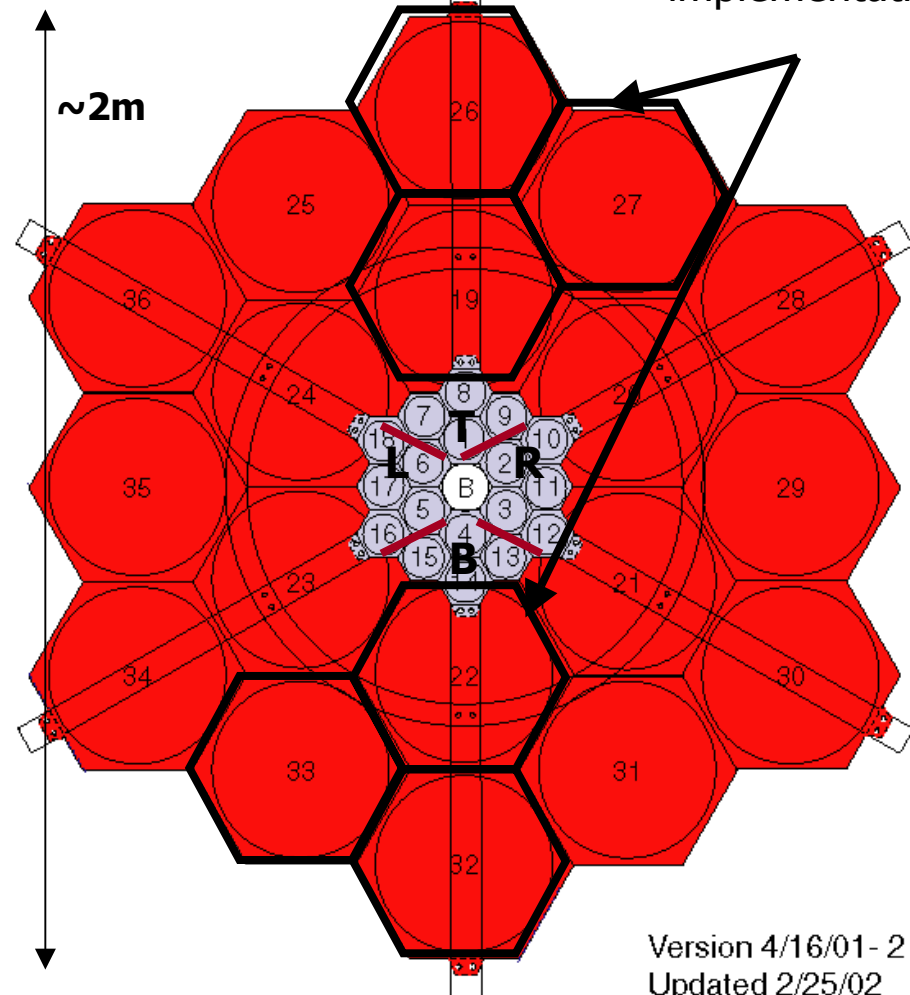
Schematic side view of STAR



Beam-Beam Counters Instrumentation

STAR Beam-Beam Counter Schematic
Front View

FY02
implementation



- 1 cm thick scintillator SCSN81 (Kuraray)
- 4 optical fibers for light collection
- 1,2 or 3 tiles connected to a PMT
- 15 photoelectron/MIP

Small hexagonal annulus:

- inner (outer) diameter 9.6cm (48cm);
- of 18 pixels, covering $3.3 < |\eta| < 5.0$ and $0 < \phi < 2\pi$
- 8 PMT (4 PMT per η ring) feasible **azimuthal segmentation: Top/Bottom/Left/Right**
- timing information, used for triggering

Large hexagonal annulus:

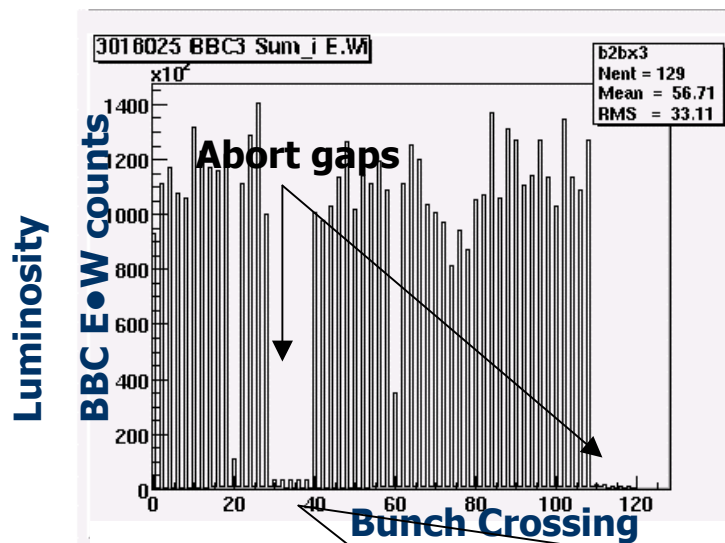
- 1/3 installed in FY02, to be completed for FY03.
- inner (outer) diameter 38cm (193cm); of 18 pixels; it covers $2.1 < |\eta| < 3.3$, no timing information
- 1/3 installed in FY02, to be completed for FY03.

BBC East * BBC West (E.W) coincidences condition – suppresses beam-gas background
-> used in each of pp trigger , defined luminosity in STAR

Luminosity Monitoring and Relative Luminosity Measurement

Scaler Board System:

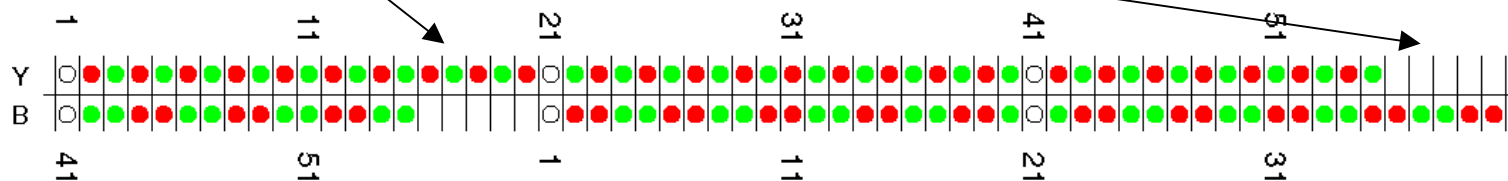
- Each scaler board has 24 input bits = 7(bunch crossing) + 17(physics inputs) $\rightarrow 2^{17}=10^5$
Example: one physics bit is the **"luminosity" bit, coincidence between signal from BBC's on either side of STAR magnet**
- Input bit pattern (information from fast STAR detectors) recorded for each RHIC Strobe received (every 107 ns)



- To determine the relative luminosity of bunch crossings with different polarization directions
- abort gaps \rightarrow beam-gas background

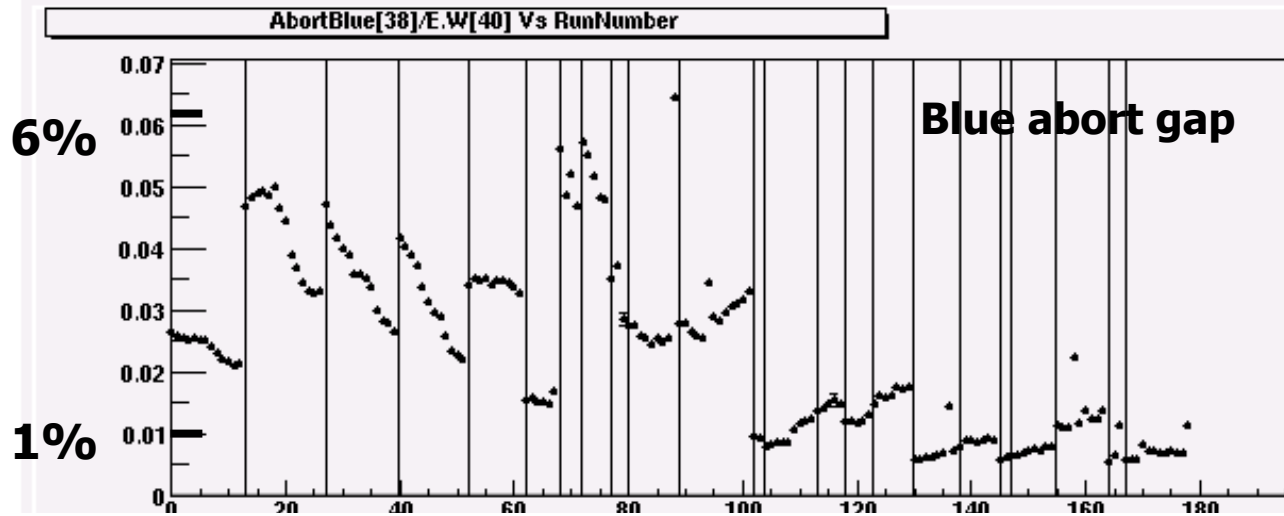
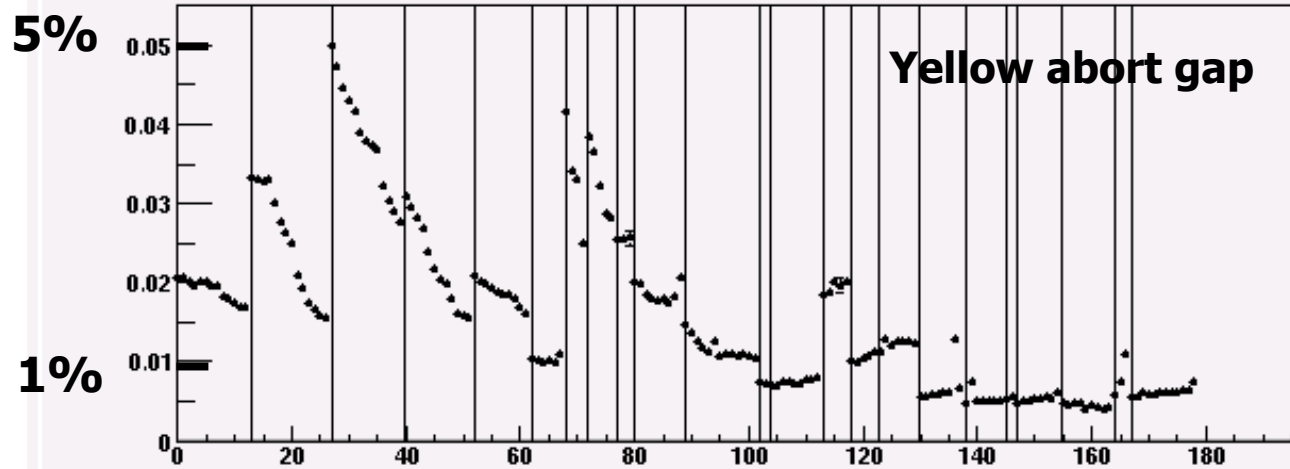
Polarization pattern at STAR:

Spin Up ● Spin Down ● Unpolarized ○



Beam-gas Background

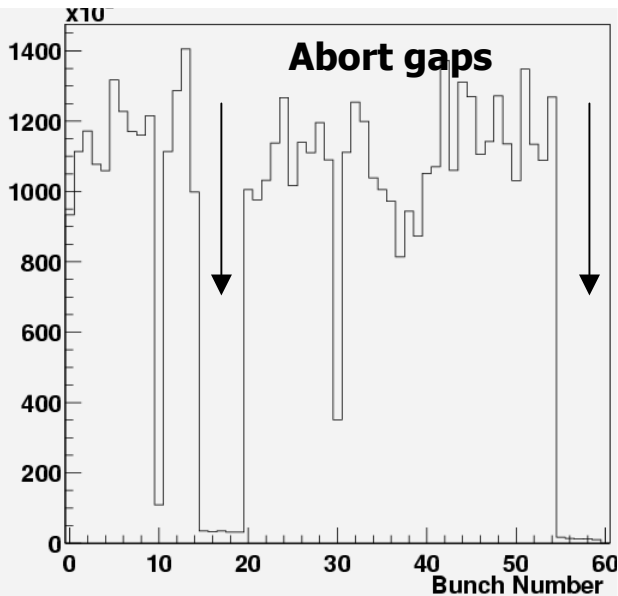
Beam-gas fraction



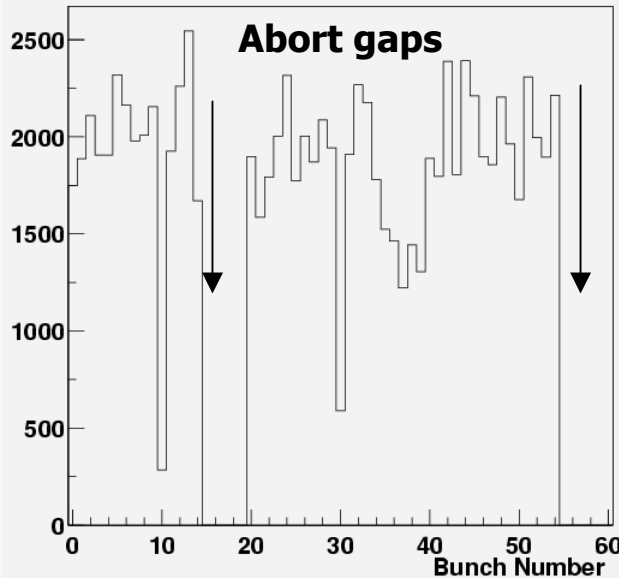
Time [Run Id]

On-line Monitoring of Beam Conditions

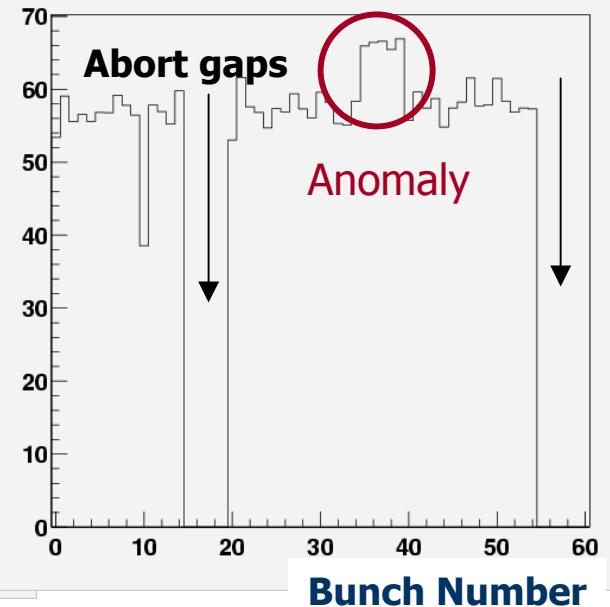
STAR Luminosity (BBC)



Product of beam intensities



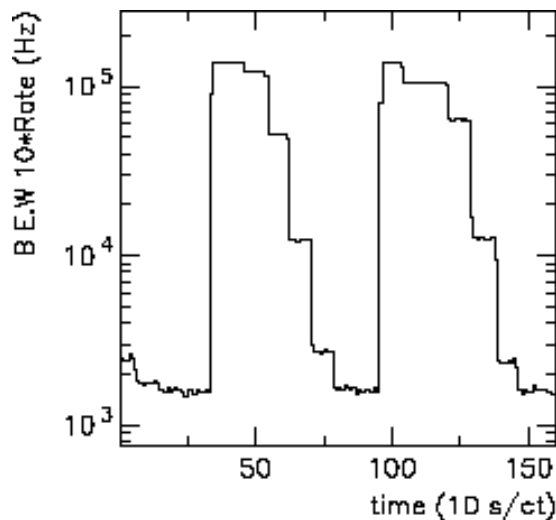
Specific luminosity



Anomaly seen at STAR in specific luminosity was confirmed by independent measurements made at other interaction points at RHIC (PHENIX, CNI polarimeter)

BBC scaler data can be used on-line to provide a feedback to RHIC accelerator group on beam conditions

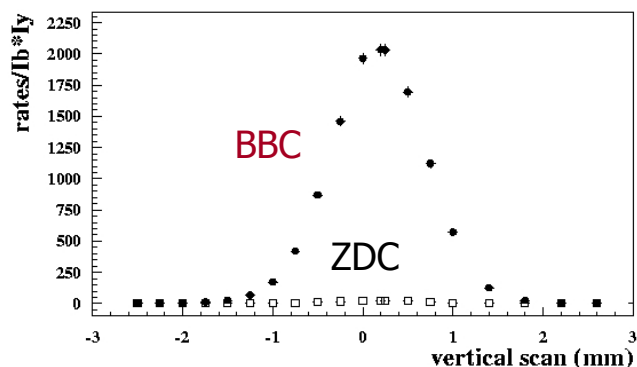
Absolute normalization from BBC E.W:



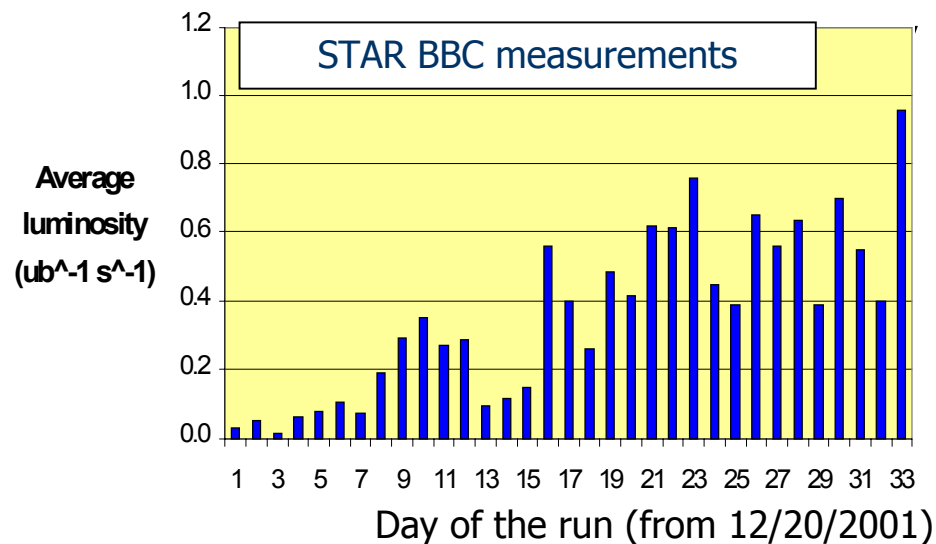
-BBC E•W coincidence rate vs time during a **Van der Meer scan** that **determines the beam size**, and hence the luminosity, by controlled relative steering of the colliding beams.

Scalar info sent to RHIC to enable MCR to steer beam at STAR

STAR pp2161



Luminosity Measurement



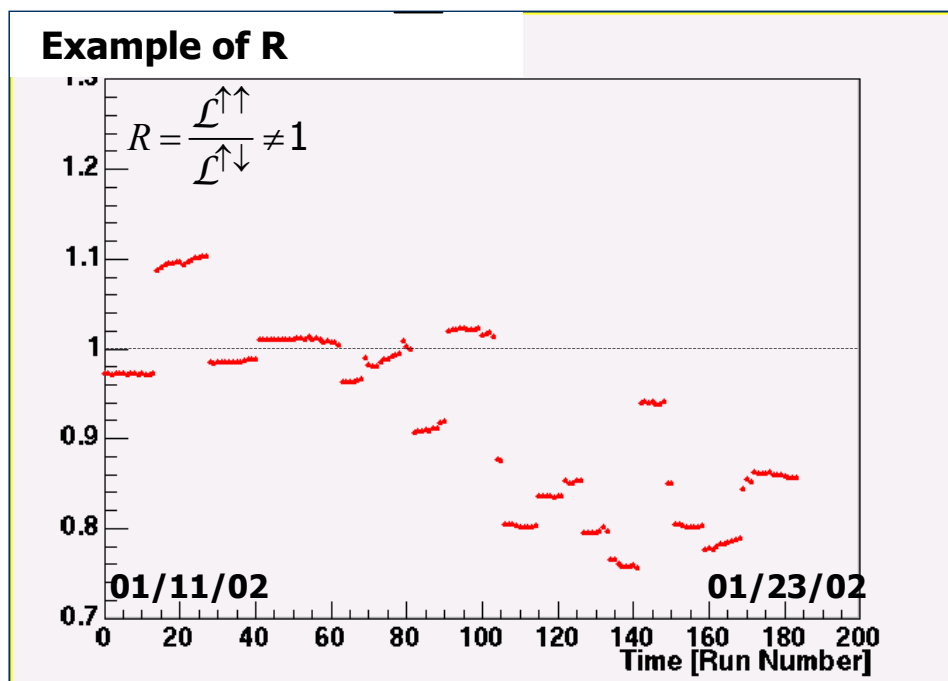
- RHIC delivers $10^{30} \text{ cm}^{-2} \text{ s}^{-1}$
- Integrated luminosity recorded@STAR $\sim 0.3 \text{ pb}^{-1}$

From simulations: BBC "sees" 40% of tot pp cross section,
Rate of 20 kHz \sim Luminosity of $10^{30} \text{ cm}^{-2} \text{ s}^{-1}$;

Agreement to within 15% - but we need to know precisely
Only relative luminosity!

Relative Luminosity Measurement

- Beam-Beam Counters – high rates
- BBC scaler information available for each STAR run; typical STAR run duration from a few minutes to several hours)
- total number of counts from the BBC scaler and used in the analysis: $N=8 \times 10^9$
- statistical accuracy of relative luminosity $\delta R_{\text{stat}} \sim 10^{-4} - 10^{-3}$

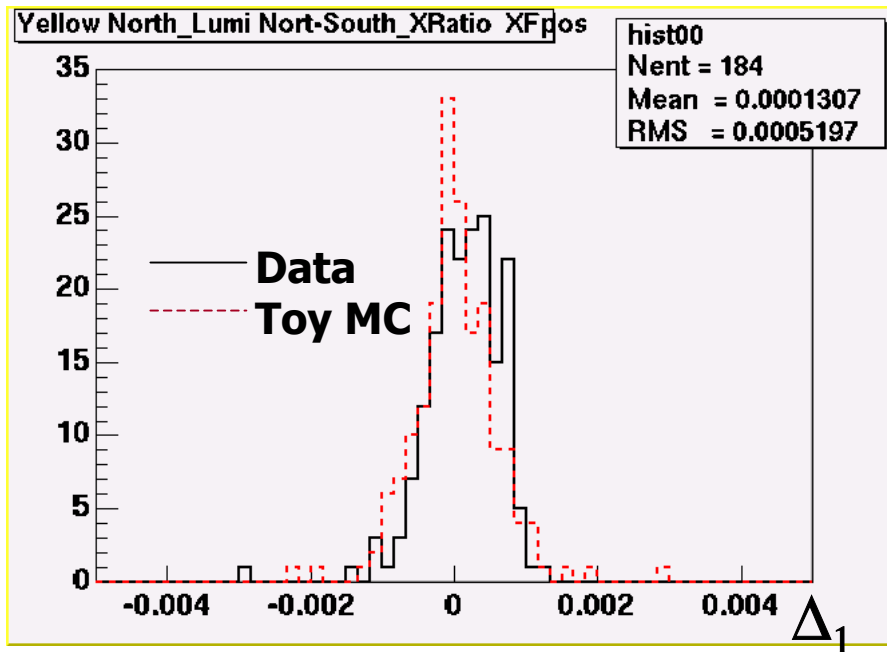


Systematic Uncertainty on Relative Luminosity

- Single transverse spin asymmetry from BBC Left/Right detectors
- Comparison of 2 methods Xratio and Luminosity Normalization methods

$$\Delta_1 = \frac{\sqrt{N_L^\uparrow N_R^\downarrow} - \sqrt{N_L^\downarrow N_R^\uparrow}}{\sqrt{N_L^\uparrow N_R^\downarrow} + \sqrt{N_L^\downarrow N_R^\uparrow}} - \left(\frac{N_L^\uparrow - R N_L^\downarrow}{N_L^\uparrow + R N_L^\downarrow} \right)$$

BBC Xratio **BBC Left**



$$\overline{\Delta} / \delta \overline{\Delta} = \pm 3.4$$

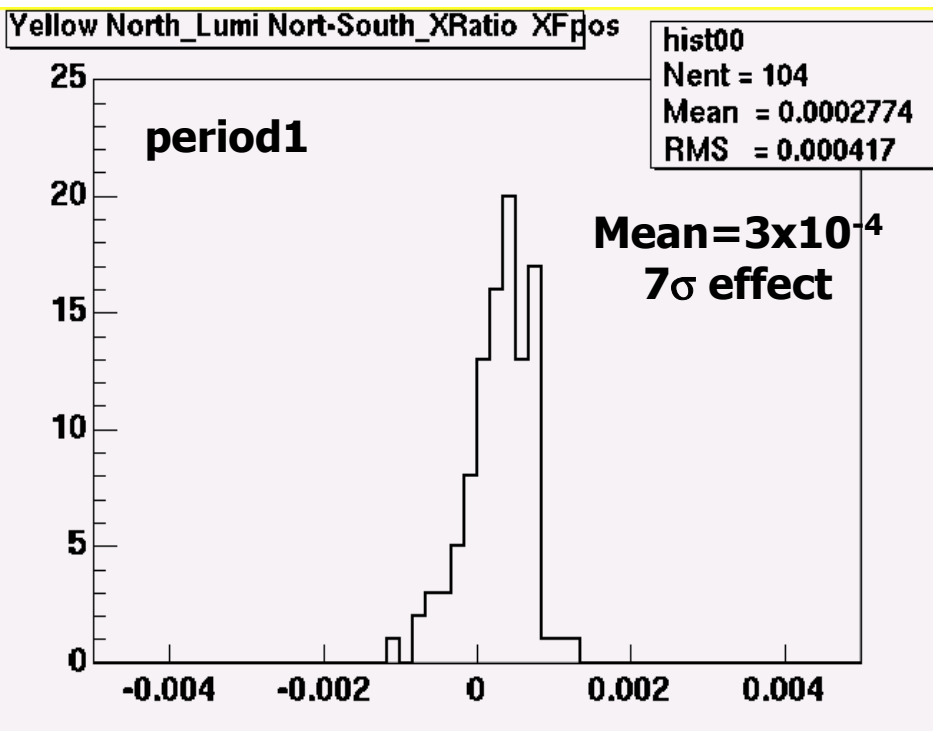
RMS is statistical in nature,
well described by toy MC

**Mean of the Δ distribution
is sensitive to δR :**
 $R = R(\text{true}) + \delta R \rightarrow \Delta \sim \delta R / 2R$

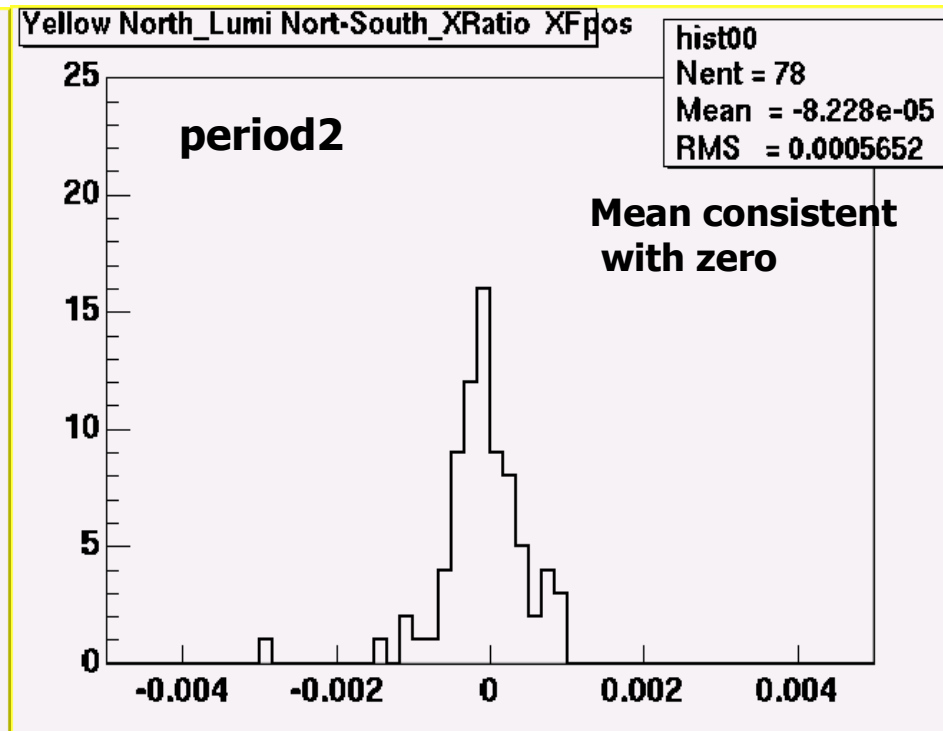
Beam-gas Background Contribution

period 1: before January 18, significant (up to 10%) beam-gas background

period 2: after January 18, small (2%) beam gas background



$$\Delta_1 \sim \delta R / (2R)$$



$$\Delta_1$$

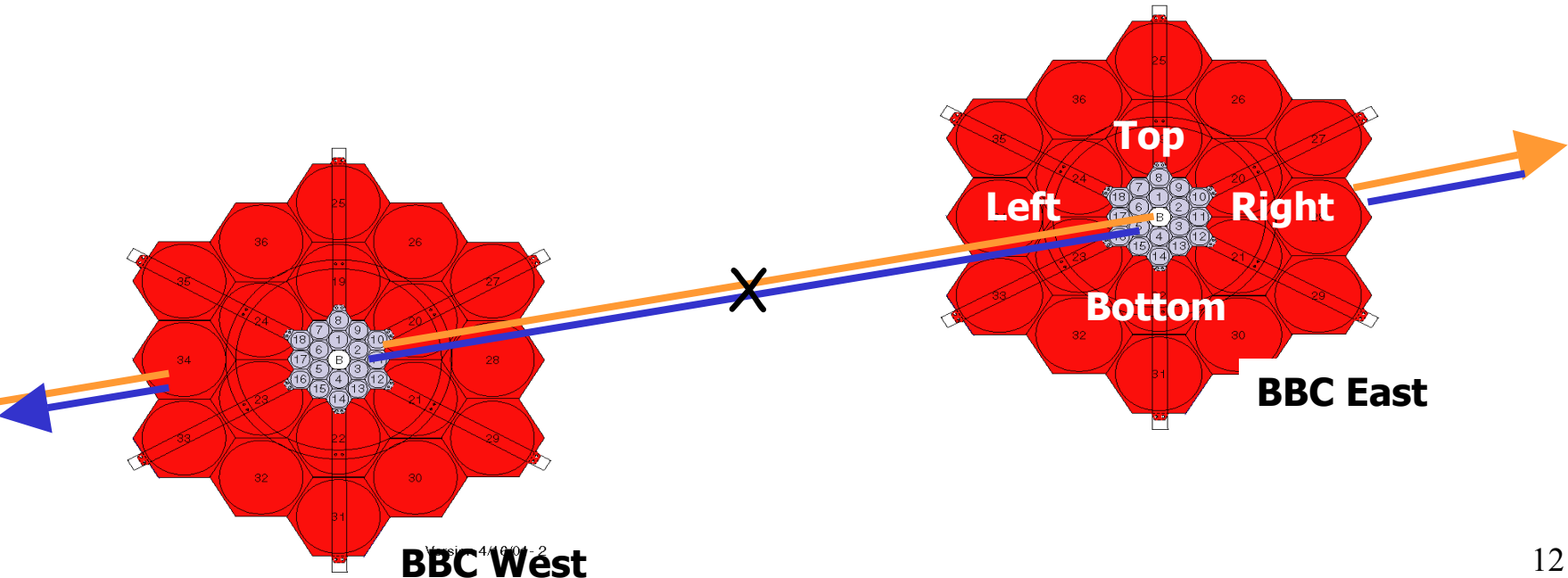
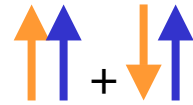
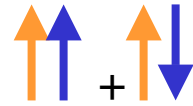
Systematic uncertainty on relative luminosity at STAR known down to 10^{-3}

Transverse Single Spin Asymmetries from the BBC

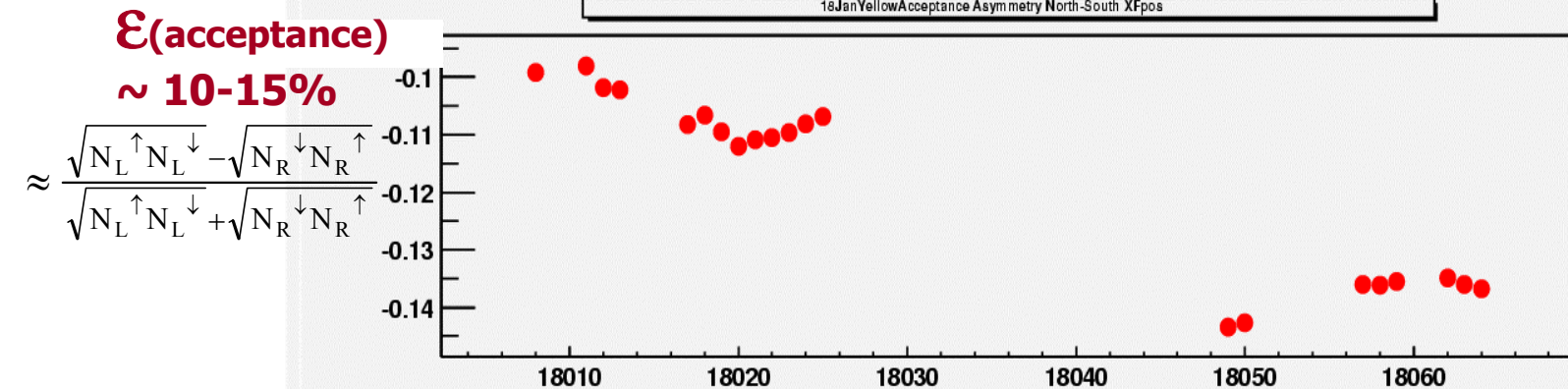
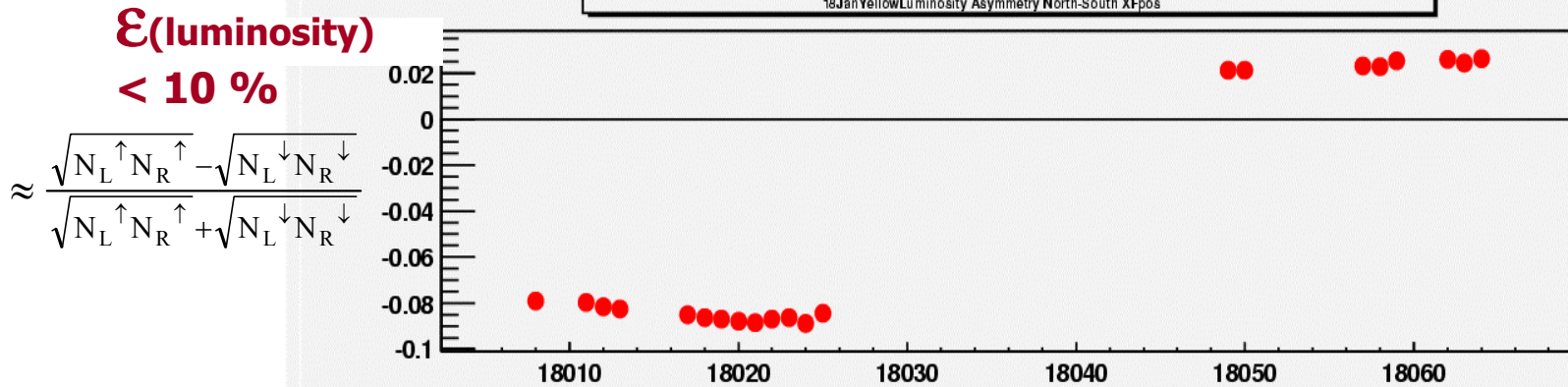
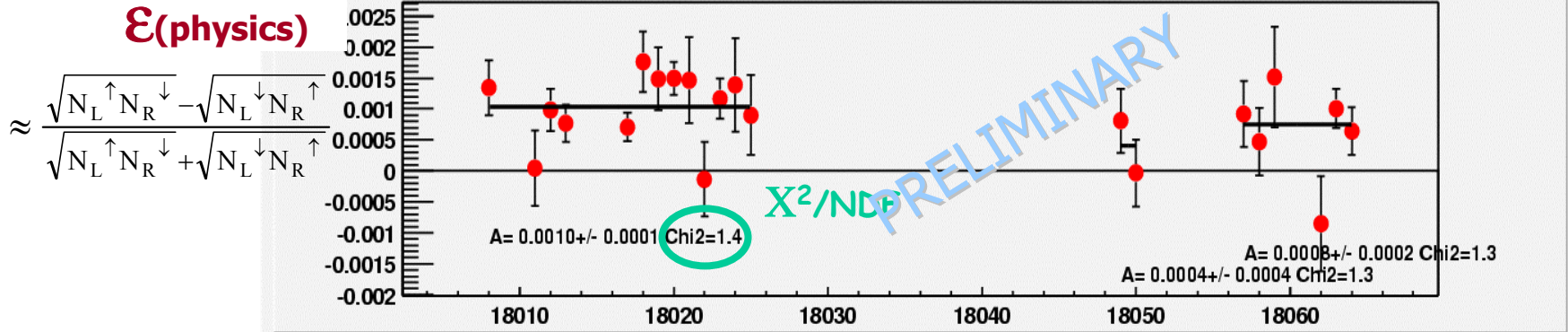
Single spin asymmetries measured in BBC East (azimuthal segments, Xratio method):
Left-Right and Top-Bottom (the latter expected to be zero)

The BBC East data sets sorted by beam polarization states:

1. **Polarized Yellow beam** (sum over Blue beam polarization states)
heads towards the East, $x_F > 0$
2. **Polarized Blue beam** (sum over Yellow beam polarization states)
heads towards the West, $x_F < 0$



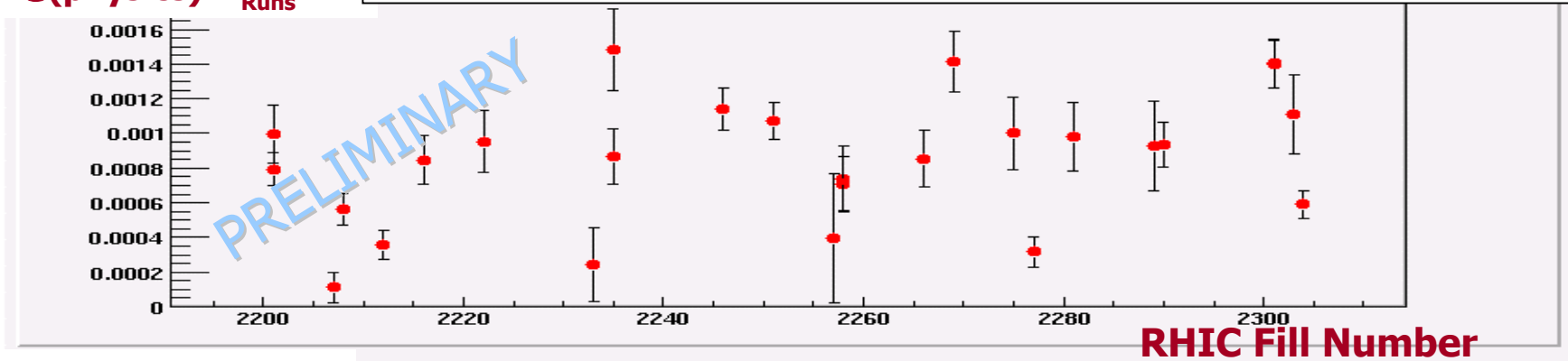
$\mathcal{E}(\text{BBC})$ Left-Right, BBC East ($x_F > 0$), vs RunNumber



STAR data from January 18 (3 RHIC stores)

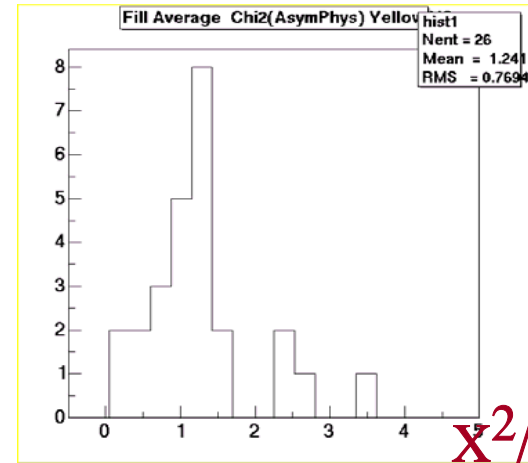
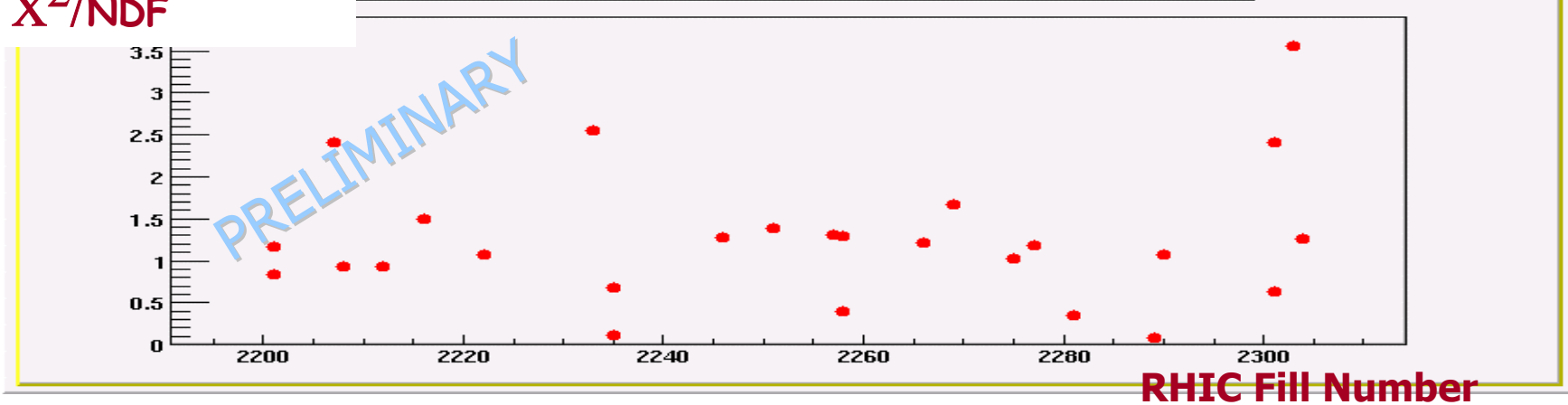
< $\mathcal{E}(\text{physics})$ > ^{Runs}

Left-Right, BBC East ($x_F > 0$) vs Fill INumber



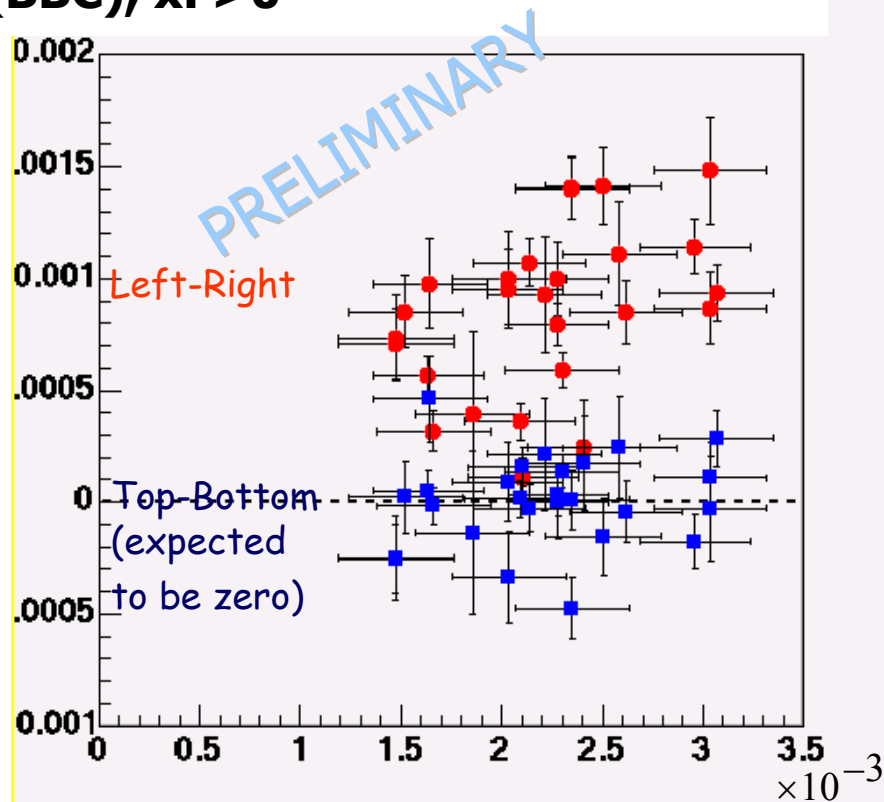
χ^2/NDF

Yellow, North-South: χ^2 for AsymPhys Fit vs Fill Number XFpos



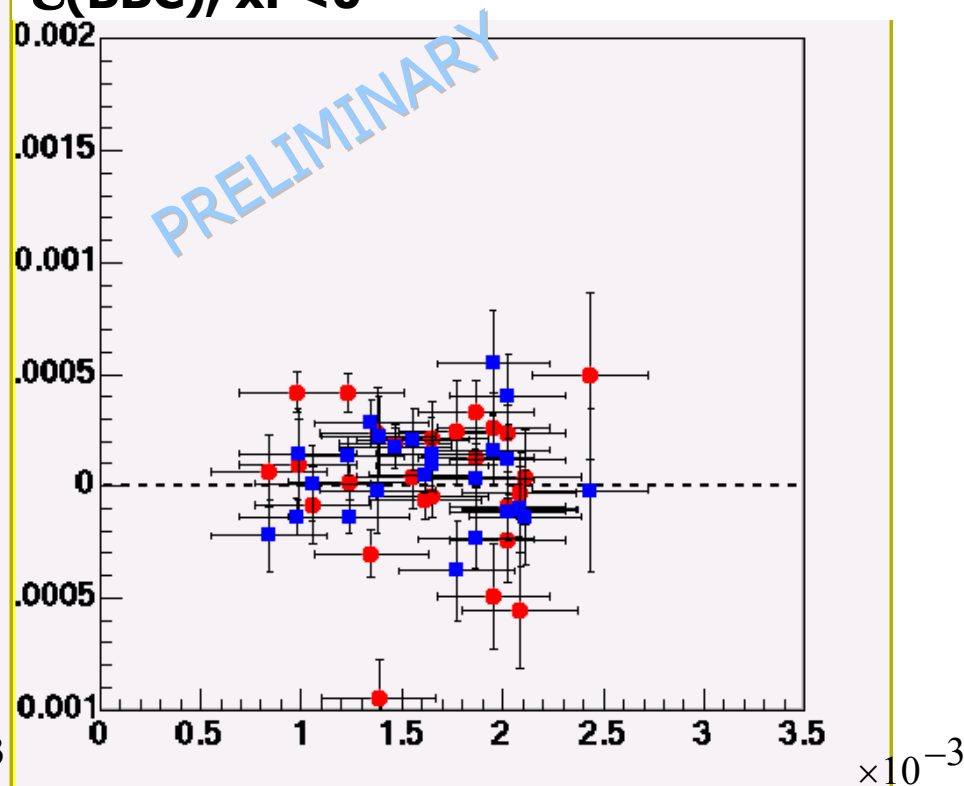
Transverse Single Spin Asymmetries from the BBC

$\mathcal{E}(\text{BBC}), x_F > 0$



$\mathcal{E}(\text{CNI})$ (Yellow)

$\mathcal{E}(\text{BBC}), x_F < 0$



$\mathcal{E}(\text{CNI})$ (Blue)

Spin effects are of the order of 10^{-3} , comparable with those observed by CNI

Only statistical uncertainties on the CNI and BBC asymmetries shown.
 BBC asymmetries: point to point systematic uncertainty is $\sim 3 \times 10^{-4}$,
 overall systematics under study

Summary

1. The Beam-Beam Counter (BBC) in STAR is a good luminosity monitoring detector. **The relative luminosity during the first (transversely) polarized proton-proton run is known at the level of 10^{-3}**
 - statistical uncertainty: 10^{-4} - 10^{-3}
 - systematic uncertainty (beam-gas background) $< 10^{-3}$

2. **Single transverse spin asymmetries measured with the BBC are of the order of 10^{-3} . Systematic effects need further studies.**

The BBC can possibly be used next year (in addition to the Forward Pion Detector) for tuning the STAR spin rotators (critical for the measurement of $A_{LL} / \Delta G$)

3. The BBC scaler system will be used to provide on-line feedback on the beam conditions to the RHIC accelerator group.